ACKNOWLEDGMENTS

This Paper has benefited greatly from discussions and suggestions by G. M. Northrop, J. D. Tupac, and W. H. Ware. Responsibility for its contents remains, however, with the author.

KEEPING THE UPPER HAND IN THE MAN-COMPUTER PARTNERSHIP

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INTRODUCTION

Augmenting Creativity

The scarcest resource in the aerospace field is the creativity of the human mind. To confirm this statement, one need only consider the engineering want ads in the Sunday paper, or the life-support cost of using man's creativity in space.

How can we increase our pool of creativity? Education provides one solution, but a long-term one. Another solution is to relieve the aerospace engineer or manager of some of his rotework† and give him more time to think about what he's doing.

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With minor variations this Paper appeared as the lead article in a special computer issue of Astronautics & Aeronautics, April 1967.

†We shall use the term rotework to describe work which is routine and unchallenging, but which consumes one's full or near-full concentration. As this varies from person to person and from job to job, a more precise definition is impossible. Some typical examples, however, are transcribing data, computing one's position from observations, or finding an item somewhere in one's office.

This is where the computer comes in. The computer can do most rotework very well at tremendous speed. Properly programmed, it can take care of the rotework involved in solving a problem, and leave the man free to concentrate on the creative aspects. Further, its tremendous symbol-manipulating power affords new dimensions to creativity which man alone could never attain.

Computer Characteristics

However, the little phrase "properly programmed" is a major obstacle. As most people know from experience by now, the computer is a very literal-minded beast. It does precisely what it's told, and no more. And, as yet, nobody knows how to tell the computer precisely how to adapt to human thinking patterns. We don't even know how to distinguish between rotework and creative work (in fact, the computer itself has called some of our definitions into question by performing jobs, such as solving complex scheduling problems, which had been considered highly creative). Computer hardware limitations in cost and performance inhibit one's power to implement large, complex programs. And computer programming itself has been more of a "black art" than a science.

As a result, most computer support up to now has been fairly inflexible. However, we are currently experiencing rapid advances in hardware performance, and learning a great deal about how and how not to provide flexibility in computer systems. It now appears that an intimate man-computer partnership in solving difficult aerospace problems will become a reality in the next few years. Figure 1, produced by W. A. Fetter and his associates on an

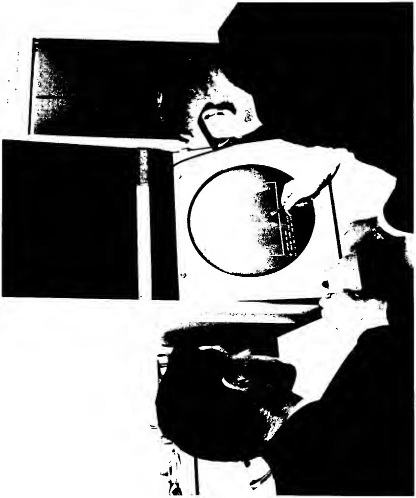


Fig. 1--Man-Computer Partnership: An Experimental System

experimental system at Boeing's Airplane Division, shows one type of man-computer partnership which may become operational within a few years. Another is indicated by an unusual "pseudo-color" processing technique discussed by Gazley, Rieber, and Stratton [1].

Artificial Intelligence

How far will the computer go in relieving man of his problem-solving duties? Nowadays, there are very few people left who predict that the computer will supply all of man's creativity, leaving him with nothing to do. Ten years ago, such extrapolation was rife, but since then people have learned that their brain processes are much harder to simulate on a digital computer than was first imagined.

A lively debate on the ultimate limits of artificial intelligence still goes on; see, for example, the articles by Minsky [2] and Dreyfus [3]. Currently, though, many erstwhile artificial-intelligence researchers have taken a pragmatic turn, attempting to exploit the manner in which the brain solves problems in various forms of man-computer partnership. However, there are still some misleading holdovers, such as the use of the term "design automation" instead of "computer-aided design."

The AIAA Computer Subcommittee

The series of articles in the April 1967 issue of Astronautics & Aeronautics is an attempt to tell aerospace professionals where we stand in achieving the goal of man-computer partnership, and to point out some of the

implications to current aerospace problem-solving practice. The series was put together by the members of the AIAA Technical Subcommittee on Computers, a subcommittee of the Guidance and Control Committee which has recently been established as a focal point for the extensive use of computers in the aerospace field. Through articles such as these, sessions at AIAA meetings, and liaison with computer societies, the Subcommittee hopes to bring the aerospace professional in closer touch with computer trends, and to acquaint the computer specialist with aerospace computational needs.

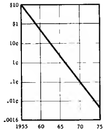
HARDWARE TRENDS

Large-Scale Integrated Circuits (LSI's)

At the forefront of the expansion of computer capabilities is the rapid increase in hardware performance. Alonso and Randa [4] describe the large-scale integrated circuit (LSI), which can contain thousands of active electronic elements on a single small silicon chip. These chips can be inexpensively and reliably batch-fabricated using vacuum deposition techniques. According to Alonso and Randa, LSI's will allow hardware designers to pay more attention to software needs, permit peripheral devices such as attitude display systems to become more autonomous, and introduce computer capabilities to even simpler devices such as altitude meters.

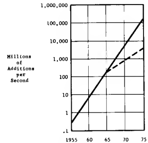
Hardware Performance

For ground-based systems, Figs. 2-5 show some estimates of the probable trends of computer central processing



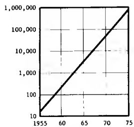
COST
CPU/Storage cost in dollars per million additions

Figure 2



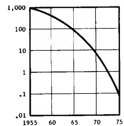
COMPUTING POWER IN THE UNITED STATES

Figure 3



SPEED
CPU/Storage speed in thousands of additions

Figure 4



SIZE
CPU/Storage size in cubic feet

Figure 5

unit (CPU) power over the next ten years [5]. By 1975, due primarily to LSI advances, we may expect to see CPU speed increase by a factor of 200, CPU size decrease by a factor of 1000, CPU costs decrease by a factor of 500, and total U.S. computing power increase by a factor of 1000. Figures 6, 7, and 8 show the trend in size [6]. Figure 6 shows what switching circuits looked like in the early 1950s. Figure 7 shows one type of contemporary circuit technology, the so-called solid-logic module, containing both printed and deposited circuits. Figure 8 depicts an integrated circuit. The small square in the center is the circuit proper; the rest is external connections and mechanical packaging. A pencil indicates the scale in Figs. 6 and 7; a needle and thread in Fig. 8.

At the very minimum, better hardware lets us compute our current solutions more cheaply and quickly. More significantly, it allows us to structure more flexible computer systems while retaining computational efficiency. This process is also aided by the rapid strides being made in the development of fast, large-capacity peripheral storage devices such as drums, disks, and magnetic card memories. Drum and disk systems are now available with billion-bit capacities, 100 millisecond average access times, and block transfer rates (in and out of central memory) of 100,000 words per second. Also, new terminal devices employing electronic and photo-optical methods are being developed, providing an input-output capability which is not only faster and more reliable but often also, as in the case of graphic input devices such as the light pen and RAND Tablet [7], a more natural way to communicate.

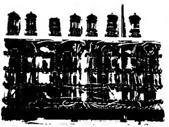


Fig. 6

Fig. 7

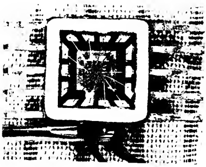


Fig. 8

Computer Organization Trends

Aided by LSI capabilities, new methods of organizing computers are maturing. For instance, the multiprocessing concept employs several processors, connected with memory in such a way that a program can be executed by whichever processor is free at the time. Potential benefits of multiprocessing are speed, since execution is in parallel instead of serial; flexibility, since processing modules can be added without a complete redesign; and reliability, since the redundant processors allow the system to "degrade gracefully."

Alonso and Randa [4] indicate, however, that the full benefits of LSI and multiprocessing will not be available until several knotty problems are solved. These include LSI standardization, testing and cooling procedures, and organization of multiprocessors to provide graceful degradation while retaining efficiency.

MAN-COMPUTER PARTNERSHIP ON-BOARD

The On-Board Information Explosion

One of the unavoidable burdens which accompany the solution of complex problems is the information explosion--the barrage of facts which can't be completely ignored because they might perhaps have a bearing on the solution. Evidence of the information explosion in aerospace is readily available not only in the document-packed library, but also in the instrument-packed control panel of today's airplane or space capsule.

The computer is our prime hope for containing the information explosion. But the containment process must be approached with great care, for the computer is far more prolific at producing useless information than are other sources.*

The extent of the information explosion for vehicle-borne systems is shown graphically by Vacca, Phipps, and Burke [8]. As they indicate, the containment problem is growing rapidly for spacecraft due to increased experiment complexity, longer mission times, and larger crews--involving more life support and monitoring functions--and for aircraft due to increased speeds, traffic, and capacity. Taking a manned Mars mission as an example, they show the many and varying data processing requirements for life support, experiments, and equipment monitoring, which would be encountered during the trip. The need for high reliability, flexibility, and efficiency again draws attention to the multiprocessing concept as a possible solution.

Real-Time Operations

In both airborne and spaceborne applications, the computer has the added burden of operating in real-time. As anyone knows who has inadvertently picked up last week's newspaper (or wished he could see a copy of next week's newspaper), the value of information has a way of degrading with time. For some information, the curve

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*In particular, system developers must beware of solutions with positive feedback components which stimulate people to produce more and more words and numbers to clog the system, in the same manner as building freeways stimulates more people to drive and clog the urban transportation system.

looks like Fig. 9, for others it looks like Fig. 10 [9]. A real-time computing system produces information which degrades in the manner of Fig. 9, forcing the system to satisfy a particular operational response time to be of any value. This is certainly a requirement for effective computer partnership with an aircraft or spacecraft pilot, and for interfacing with a control system which requires computer-processed inputs every few milliseconds. Real-time operation imposes greater performance demands on both hardware and software, and places tight constraints on the attainable flexibility of the system.

CONVERSATIONAL COMPUTING

On-Line Systems and Computer Graphics

Ground-based computer systems have also been grappling for some years with the problems of real-time operation; first in process control for chemical reactors and milling machines and in hybrid analog-digital controls and simulations, and recently in an attempt to make the computer more directly available to people with problems to solve.

This latter concept, the on-line interactive computing system, gives strong promise of achieving significant man-computer partnership. Combined with the expanding capability to communicate graphically with the computer, allowing the user to make direct use of his geometric intuition, this "conversational mode" of operation holds great potential for increasing the creativity and productivity of the aerospace engineer, reducing design costs and lead-time, and improving management, configuration control, and production techniques.

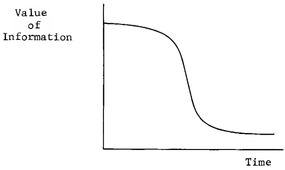

Fig. 9--A Real-Time System

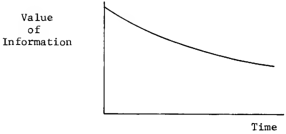

Fig. 10--A Non Real-Time System

The article "On-Line Systems and Man-Machine Graphics" by Chasen and Seitz, with contributions by Fetter [10], surveys the turmoil of activity in the field and examines current progress toward achieving the above goals. Interactive graphics systems are being used successfully in several problem areas: structural dynamic analysis, electronic circuit analysis, telemetry data reduction, numerical-control part programming, and parts planning. Other problem areas such as aerodynamics, propulsion system design, vehicle preliminary design and analysis, plant layout and information retrieval also look ripe for the interactive graphics approach in the near future. Interactive systems are also beginning to penetrate and change the techniques of engineering education. Further applications, with an even stronger real-time flavor, involve computer aids to control of large, complex systems: air traffic control, space mission control, military command and control.

Implementation Problems

However, the road to good interactive systems is strewn with numerous obstacles. The software problems--channeling information flows, providing flexible communication languages, "idiot-proofing"--are extremely complex. Experienced programmers are scarce. Terminals are expensive, but they must appear to be free goods to users, as people don't think as well with other impatient users or beady-eyed accountants looking over their shoulders.* Potential

*The on-line interactive mode isn't totally new. Computers were operated almost exclusively in this way up to the mid-1950s--everyone ran his own programs directly on

gains are difficult to quantify, creating tough managerial decision problems.

Not the least of the obstacles is the morass of new terminology--time-sharing, on-line, multi-access, remote processing--created to describe various modes of operation. Each specialist seems to have his own definitions (often virtually incomprehensible) of these terms, leaving the nonspecialist with no firm ground on which to base comparisons. Probably the most useful definitions so far are those supplied by Rosenberg in an article on time-sharing [11]; they are reproduced here for reference, as they are used in other articles.

> Multiprogramming--Several independent, but perhaps related, programs or routines concurrently residing and operating in an interleaved manner with a single computer system.
> Multiprocessing--Several program processes executing simultaneously within a computer configuration consisting of two or more (hardware) processing elements.
> Real-Time Processing--Program execution to satisfy a particular operational response time, which may range from microseconds to seconds or minutes.
> Interactive or On-Line Processing--Human user or device serviced by a computer system through direct communication with an operating program. For human users, this includes "conversational" interaction.
> Remote Processing--User input/output devices are connected by communication facilities to a remotely-located computer system.
> Multiple-Access--A number of on-line communication channels provide concurrent access to a common computer system.

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the machine. But, due to an esoteric and inflexible communication language (numerical machine language), and strong economic pressures to get off the machine as quickly as possible, it was generally an unsatisfactory way to solve problems.

The definition of time-sharing itself varies even more than the others. Corbató et al., give a fairly good one [12]:

> Time-sharing can mean using different parts of the hardware at the same time for different tasks, or it can mean several persons using the computer at the same time.

As illustrated in Fig. 11 [6], the point of time-sharing in interactive systems is to use the computer's extra speed to give each of several users the feeling that he has the entire machine at his disposal--without having to buy each a separate machine. Note that if machines become cheap enough, each user can have an interactive system on his own computer, eliminating the need for time-sharing.

Changing One's Problem-Solving Methodology

I can personally testify to the increased productivity and creativity provided on some jobs by conversational computing. Recently, I used RAND's JOSS* system [13] on a problem involving orbital coverage patterns, and found that the way I went about solving the problem was strikingly different. I could experiment with parameters--earth oblateness, lunar effects--in a small way before having to decide how to incorporate them into a larger model, rather than having to make a number of critical judgments at once and cast each in concrete. Thus, as I went along, I was able to take the bugs out of my conception of the problem, as well as out of the program. (JOSS is a typewriter-based system; Fig. 12 gives a simple JOSS conversation.)

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*JOSS is the trademark and service mark of The RAND Corporation for its computer program and services using that program.

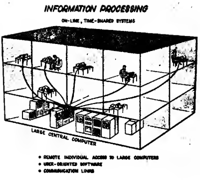
INFORMATION PROCESSING
ON-LINE, TIME-SHARED SYSTEMS
LARGE CENTRAL COMPUTER
• REMOTE INDIVIDUAL ACCESS TO LARGE COMPUTERS
• USER-ORIENTED SOFTWARE
• COMMUNICATION LINES

Fig. 11

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* A simple JOSS conversation.  User types in green.  JOSS replies in black.
Lines beginning or ending with an asterisk are considered commentary only.*

Type time.
        time:  09:58
 Type 3.1416+2.7183.
3.1416+2.7183 =         5.8599
 Type 3.1416+e.
e = ???
 Set e = 2.7183.
 Type 3.1416+e.
    3.1416+e =          5.8599
qwertyuiop
Eh?

* Solving a transcendental equation.  Kepler's equation:  M = E - e sin E.
*  Find E, given M = 1.210, e = 0.260.

1.1 Set M = E - e·sin(E).
1.2Typw*
1.2 Type E,M in form 1.
Set e = 0.260.
Do part 1.
Error at step 1.1:  E = ???
 Set E = 1.
Do part 1.
Error at step 1.2:  I can't find the required form.

Form 1:
        E = _.___          M = _.___
Do part 1.
        E = 1.000          M =  .781

Do part 1 for E = 1.1 (.1) 1.5.
        E = 1.100          M =  .868
        E = 1.200          M =  .958
        E = 1.300          M = 1.049
        E = 1.400          M = 1.144
        E = 1.500          M = 1.241
* By inspection, I can see that the answer is about E = 1.47.
Do part 1 for E = 1.468 (.001) 1.472.
        E = 1.468          M = 1.209
        E = 1.469          M = 1.210
        E = 1.470          M = 1.211
        E = 1.471          M = 1.212
        E = 1.472          M = 1.213
* The solution, to three decimal places:  E = 1.469.

Type time.
        time:  10:05
Type users.
       users:  17
* There are now 16 other people simultaneously using JOSS.
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Fig. 12--A Simple JOSS Conversation

As a subjective judgment, I think I gained a better grasp of the problem in a few hours with JOSS than I would have in a couple of weeks with our FORTRAN-batch system. The only rotework I can recall was some elementary algebraic symbol manipulation and constructing some graphs.

As the article by Chasen and Seitz [10] indicates, these two capabilities--on-line graph construction and elementary symbol manipulation--are within the grasp of current computer technology. Of course, it would also be nice to have a system which could understand voice inputs and hand-waving. But these are still too far out to plan for now.

THE COMPUTER DOWNSTAIRS

Diversity and Change

Conversational computing, however, is not a panacea for all computational problems. And at present it occupies but a small corner of the aerospace computing facility, which is also busy providing a bewildering variety of services to the company at large: computing aerodynamic characteristics of a future vehicle, simulating the logistics of installing and operating a new system, processing telemetry data, running the payroll, controlling machine tools, keeping track of materiel inventories, sequencing equipment checkout tests, optimizing trajectories, and simulating vehicle dynamics on a hybrid analog-digital hookup.

"The Computer Downstairs," authored by Grosch with the assistance of L. H. Amaya, R.M.L. Baker, E. Levin, and G. M. Northrop [14], describes how the computing

facility evolved into what it is now, and points out some of the problems involved in managing such a dynamic and diversified operation. Equipment is difficult to evaluate but must be replaced constantly--while maintaining continuity of service. Projects, priorities, and personnel are in a continuous state of flux. And the impact of new technologies such as interactive graphics must be evaluated, provided for, and related to users and higher management.

New Directions

Fortunately, such dynamic management problems aren't completely new to the aerospace industry, which has rapidly developed organizational and managerial tools to cope with them. This experience has placed aerospace in a favorable position to study similar problems arising in medicine, urban planning, and crime prevention. In turn, the computer facility is presented with an even wider variety of jobs to handle in the future.

Grosch [14] also points out some other probable functions of the future computer center: centralized data storage, retrieval, and communications processing, along with the underlying requirement of English language processing. This latter has turned out to be a much more formidable problem than originally envisioned. However, by factoring out some of the more difficult semantic problems, it appears possible to create forms of "reduced English" suitable for man-computer interaction in particular contexts.

Social Implications

Another problem underlying the centralized multiple-access data base is that of ensuring security and privacy of information [5,15]. The computer represents a strong threat to the sanctity of personal and proprietary information. On the other hand, it also represents a golden opportunity to curb current malpractices in a unified way. How we resolve this, and similar social problems of automation, depends on our capabilities as computer system developers and users to maintain a continual awareness of social implications, and to provide and advocate solutions respecting human rights.*

Even more vital is our responsibility to keep future engineering and computer professionals from becoming overly narrow-minded specialists. A course on "Social Implications of Technological Advances," studying problems raised in such books as 1984, Brave New World, and Silent Spring, should be a part of every science or engineering student's curriculum.

Numerical Analysis

The new methods of computer operation are providing strong stimuli to numerical analysis. Going interactive doesn't avoid roundoff and truncation errors, it just makes one aware of them faster. Further, there is a pressing need for faster algorithms; the man sitting at

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*McCarthy [16] points out that we may have to re-examine the concept of human rights. For example, do we have the right to keep people from keeping files on us?

the console wants his answers now. As a result, we may see more use of semi-analytic approximations such as the ones used to estimate boost vehicle performance.

The availability of multiprocessors and huge computer memories will cause a reordering of the utility of numerical algorithms. The old problem of tabular versus polynomial and rational function approximation will have to be rethought again. And, as mentioned in the article by Chasen and Seitz [10], interactive graphics may provide mathematicians with new geometric insights into the performance of numerical algorithms.

Software

While the production of computer hardware becomes more automated and prolific, and while the demand for combinations of hardware and software increases apace, software--the programs which tell the hardware what to do--remains essentially a handicraft industry. There is a strong need for more natural problem-oriented languages; programming languages and operating systems with more helpful debugging features; acceptable programming standards; and more understandable documentation [17].

One encouraging trend is that interactive graphics is being applied to the programming process itself, in systems for on-line debugging and flow-chart manipulation. Another is that larger efforts are being made to reduce duplication of effort in applications programs. Outstanding in this regard is Project COSMIC, set up at the University of Georgia, in Athens, Georgia, by the NASA Office of Technology Utilization, as a clearing house for aerospace computer programs. One does not need to be a NASA contractor

to submit or request programs, although a nominal fee is charged for servicing requests. I should like to encourage extensive use of this facility, as program interchange reduces duplication of effort, and stimulates the comparative evaluation of programs and the establishment of realistic programming standards.

Be warned, however, that using a program written by someone else is a lot like flying an unfamiliar airplane. If there aren't any standards to rely on, you can get hurt very quickly. There is one difference. On the computer, you may not realize you're hurt until much later.

SYSTEMS ANALYSIS

Procrustean Computer System

In general, computer users are having to take more and more on faith. Fewer and fewer people know in any detail how their operating systems or matrix inversion subroutines work. This trend can be dangerous, as it is very easy to misuse something you don't understand well.

In ancient Greek legend, there was a man named Procrustes with an extraordinary concept of hospitality. He placed any visitors who fell into his hands on an iron bed and proceeded to fit them to it exactly. If the guests unfortunately proved longer or shorter than the bed, Procrustes stretched or chopped them to its size.

With many current systems, getting in bed with the computer can be a very Procrustean operation! One can find that the scope and goals of his projects are truncated or distended to fit the needs of the computer.

A disturbing example of this process was recently provided by an aerospace component manufacturer. After a thorough investigation of computer usage, the company decided to make the computer less accessible to engineers. The management found a marked tendency for engineers to use old designs and their extrapolations because computer programs were available to analyze them, rather than inventing new designs. The computer, often in very subtle ways, can stimulate mediocrity rather than creativity.

Maintaining Relevance

Instances such as this indicate that the aerospace industry preaches systems analysis far better than it practices, especially when dealing with the computer. Systems analysis, best described in Ref. 18, is difficult to summarize because it is less a body of standard techniques than a state of mind. The systems analysis approach commits the analyst to a careful definition and continuous re-examination of his project's goals, to ensure that the problem he solves is the appropriate one. It also involves him in a continuous confirmation of the relevance of his efforts to the achievement of his goals, to guarantee that his solutions solve the problems he wants them to solve.

The key words are continuous and relevance. If we lose sight of them, the best we can come up with are brilliant solutions to the wrong problems. Examples of this abound in the aerospace industry. An engineer linearizes a guidance system, just to get a feel for its performance on the computer. The results are so engrossing that he investigates them further, neglecting for a while the fact

that his original problem involved nonlinearities. A few weeks later, he produces an optimized linear system which is useless because nobody can build the required linear components. An interactive computing system would help by reducing lost time to a few days, but the responsibility for maintaining relevance remains with the user.

Creativity Aided--Not Replaced

Like fire or nuclear energy, the computer must be treated with wide-awake care. It offers us a tremendous potential in augmenting our problem-solving capability--or a chance to become mentally soft through overdependence. And history records again and again the downfall of nations which become overdependent on others to solve their problems.

It is easy to become mesmerized by the computer's productivity. But productivity isn't a goal in itself. As computer users, we must continually examine our goals, and the relevance of our efforts to them, in order to maintain perspective in the face of the barrage of computer symbols. It is our responsibility to remain the senior partner in the man-computer partnership.

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KEEPING CURRENT ON COMPUTERS

Datamation magazine does an excellent job of reporting computer trends in understandable language. Computer Design magazine is good, but more hardware- and specialist-oriented. The semiannual AFIPS Spring and Fall Joint Computer Conferences generally have a good proportion of lucid, up-to-date papers and manufacturer exhibits, and publish excellent Proceedings.